A 3-D GIS and Quantitative Backscatter Analysis in Support of STRATAFORM

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LONG-TERM GOALS

Our long-term goal is to provide the fundamental mapping information and visualization tools necessary to support STRATAFORM's multidisciplinary effort to develop a more complete understanding of how short-term oceanographic and geological processes interact to produce the preserved geologic record on the shelf and slope portions of the continental margins. This effort began with detailed mapping of the bathymetry and backscatter of the STRATAFROM survey areas and is now continuing with the integration of the many data sets collected in the northern California STRATAFORM region into a GIS system that will allow all STRATAFORM researchers (and others) to interactively explore the complex relationships amongst seafloor, water-column, and subsurface parameters in an easy and intuitive fashion.

SCIENTIFIC OBJECTIVES

The fundamental objective of the STRATAFORM Swath Mapping Program is to provide complete (100%) bathymetric and sidescan imagery coverage of the Northern California and N.J. Margin STRATAFORM field areas. This has allowed STRATAFORM investigators to evaluate the geologic processes of the shelf and slope over a continuum of scales. Complete coverage also has provided STRATAFORM investigators with the knowledge that their studies are based on a complete picture of morphological relationships rather than the interpolation of sparsely spaced data. In doing this, we have produced a bathymetric, geomorphological, and potentially lithological framework upon which all subsequent work can be built. Building on these base maps we focused our efforts on the development of a fully searchable GIS system that allows us to interactively explore the inter-relationships amongst the many data sets collected by STRATAFORM investigators (as well as others). In particular we are using this approach to further develop techniques for the remote classification of seafloor materials from swath mapping data and, to develop techniques for the interactive 3D visualization of co-registered surficial and sub-bottom data.

APPROACH

The original mapping of both the northern California and New Jersey margin STRATAFORM regions was conducted with an EM1000 (95 kHz), multibeam sonar. As compared to conventional echosounders, multibeam sonars provide increased source level, lateral resolution, and a substantial increase in data density and areal coverage. Most importantly, the newer systems also provide the ability to simultaneously produce high-resolution sidescan sonar imagery. We have developed a full suite of real-time and near real-time multibeam sonar processing tools to assure that only high-quality data is collected and that this data can be processed in the field. These tools also allow for the interactive 3-D visualization of multibeam data sets and derivative products (Mayer et al, 1997) We are also developing a range of seafloor classification algorithms with particular focus on techniques that look at the characteristics of the returned waveforms as well as the change in backscatter as a function of angle of incidence (Hughes Clarke et al., 1997). We are developing techniques to fully correct backscatter data for radiometirc factors as well as looking at the effect of near-surface gas on the angular dependence of backscatter. In order to compare the results of these analyses to ground truth data collected by other STRATAFORM scientists and to explore the limits of extracting quantitative seafloor property information from multibeam sonar data, we have, for the northern California survey area, created a very large and graphically explorable data base made up of the wide range of data sets collected in the region.

The data base of information in the northern California STRATAFORM region is immense and disparate, ranging from physical oceanographic time series collected by moorings, to multichannel seismic data to backscatter and bottom photos. Our approach to understanding the complex inter-relationships of these data (and thus the potential for using remotely derived data sets like acoustic backscatter to understand the distribution of lithologies and seafloor processes) has been to treat each data set as an individual layer or theme and bring the data into a Geographic Information System. Once each layer is fully georeferenced and all geodetic corrections (projections, datums, etc) applied, we then have the ability to interactively select, explore, retrieve and display the data sets in any combinations we desire. For example we can easily look at the relationship of sediment porosity as measured on cores (or many, many other parameters) to acoustic backscatter. We have also extended the ability of the standard GIS environment to allow us to not only import data layers but to link these layers to the actual data sets (i.e. down-core property plots or even seismic data). Finally we have begun to develop a true 3-D environment for this data base so that this same sort of interaction can be done in 3-D and thus inter-property relationships can be explored within the complex of the 3-D morphology.

WORK COMPLETED

In 1995 and 1996, we completed mapping of the Calif. and most of the N.J. survey areas. In 1997 we completed the remaining deep-water portion of the N.J. study area, processed these data and merged them with the shallow water data. We also processed additional multibeam (Hydrosweep) data from the Eureka area collected by Clark Alexander. We merged this data with the earlier data sets and made the new maps available to all STRATAFORM investigators. Our more recent efforts focus on data integration, visualization and particularly on the question of remote seafloor classification. We have finalized interactive 3-D fly-throughs of both the N. J. and California margins (Mayer, et al., 1997) and have developed a suite of automated algorithms for extracting and parameterizing the backscatter as a function of angle of incidence (Hughes Clarke, et al., 1997). We have completed the software necessary to bring fully georeferenced high-resolution seismic data into our 3-D visualization package. Our focus for data integration and sediment classification studies has been the Eureka margin. Our GIS database now includes 62 layers (including several types of seismic data, gas abundance data, core and camera station data, geologic, tectonic and hazard maps, bathymetry and backscatter from a number of systems, satellite imagery, mooring data, etc.). It was distributed to STRATAFORM investigators on CD in December, 1999; software has been developed that will allow all those receiving the CD access to all features needed to explore the data base without the need to purchase a GIS system. We have completed the algorithms for the application of tree-structured wavelet transforms to multibeam sonar backscatter data and applied these transforms to data from the Eureka margin (Hou and Mayer, 1998); we have begun to bring the various data layers (including seismic data) into the 3-D environment . We have also supported the efforts of other Strataform investigators (Flood, Nitterour, etc.) by providing installation and operating advice as well as software for the processing and visualization of data collected by the new DURIP-purchased EM3000 multibeam sonar. This system has now successfully been used for a variety of programs including shallow water mapping in both the N.J. and California STRATAFORM field areas and off Panama City Florida in support of a Navy DRI.

Our most recent efforts have focused on the development of a robust model for seafloor characterization and, in particular, predicting the affect of near-surface gas on acoustic backscatter as a function of angle of incidence and concentration. Fundamental to the development of these models is the need to fully correct the backscatter data collected with multibeam sonars. In the course of the thesis work of graduate student Luciano Fonseca, we have derived a series of radiometric corrections that remove time varying and angle varying gains, calculate true grazing angle with respect to the

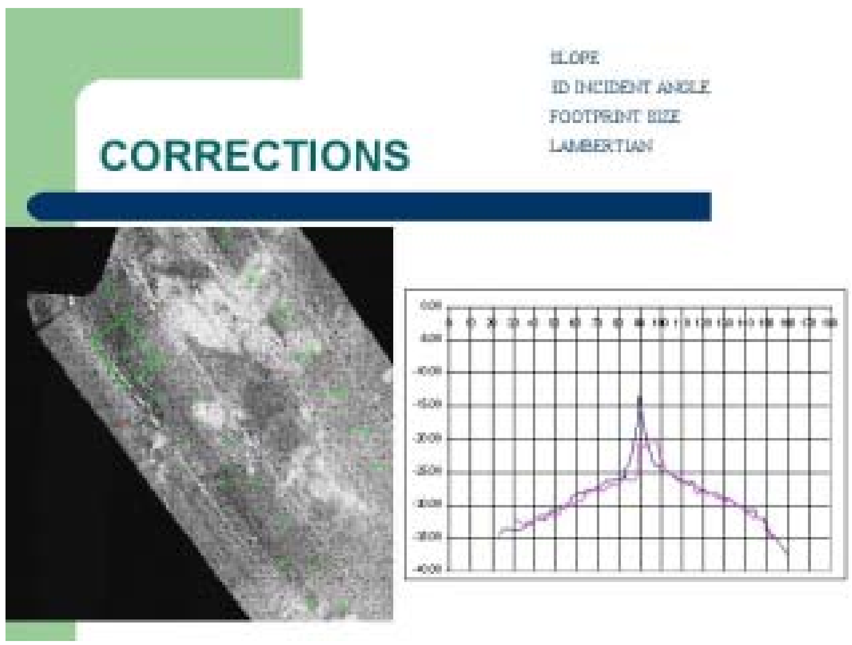

Figure 1. Interactive tool for extracting backscatter data for full corrections. Region in box (from STRATAFORM survey area) is selected. Plot at right shows backscatter across swath uncorrected for seafloor slope (curve offset from 90 deg) and the corrected curve (symmetrical around 90 deg).

multibeam bathymetry, and correct for the true area ensonified by the sonar footprint (Fig 1). We have also modified the Jackson et al. (1986) model for seafloor and volume scattering to accommodate the presence of gas bubbles (common in the STRATAFORM area). We treat the bubbles as individual scatterers that sum to the total bubble contribution. This bubble contribution is then added to the volume contribution of other scatterers. (Fig. 2). This model has now been completed and the STRATAFORM GIS has been used to identify areas where ground-truth samples are available. This work was presented at the last AGU meeting (Fonseca and Mayer, 2000) and a JASA paper has been submitted and is now under review. In addition we have now developed an interface from the 2-D GIS that we have been using for STRATAFORM data (ArcView) into the 3-D GIS environment

(Fonseca, Mayer and Paton, in press). With this interface, all of the layers of the GIS been transformed into 3-D objects and we have created a true r interactive 3-D GIS (Fig 3).

RESULTS

Numerous insights have been derived and papers written from the multibeam data. The wavelet transform has proven to be a robust technique for the removal of artifacts from backscatter data. The ability to apply full corrections (including local slope) to the backscatter data has greatly improved our ability to further process the data as all instrumental and local slope derived artifacts have been removed. Once corrected we can then compare backscatter data from regions known to contain gas (gas content has been determined on core samples and was provided by Dan Orange) to our model for backscatter as a function of gas concentration (Fig. 2). We have used the GIS to extract physical properties from cores collected in the STRATAFORM survey area and use these physical properties to model the expected backscatter as a function of angle of incidence (at 95kHz) in the area. The model predicts higher backscatter in the shallower regions with coarser sediments and low backscatter in deeper regions with finer grained sediments. The fully corrected measured backscatter shows just the unexpected relationship of high backscatter associated with the deep fine-grained sediments and low backscatter associated with the coarse shallow water sediments. There are numerous indicators of the presence of gas in this region (morphological, geophysical and direct measurements on cores) and when we apply the extended (to include the effect of gas) backscatter model to physical property data (using measured gas values) we find that the backscatter "anomalies" can be explained by the complex response of gas to changes in depth. In deep water the bubbles are acoustically "stiff" due to increased ambient pressure and thus result in high backscatter; in shallow water the "softer" bubbles tend to decrease the interface scattering (by lowering the sound velocity) and attenuate some of the volume-scattered energy (Fig 3).

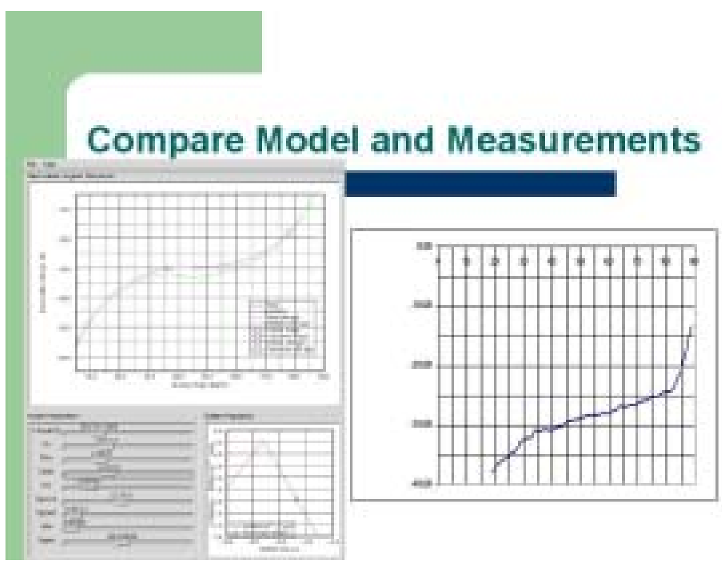

Fig. 2. Comparison of model results against field data for site in STRATAFORM field area where gas concentration measurements were made on cores (Data from Dan Orange). Model shows good agreement with actual backscatter data.

IMPACT/APPLICATIONS

The swath mapping results from the Eureka and the N. J. margins provide all STRATAFORM investigators with an unprecedented, detailed look at both the bathymetry and distribution of sediments on the shelf and slope. These results have already been used in planning the deployment of a series of long-term moorings, seismic profiling and coring cruises, as well as for planning ROV, submersible work, and ODP sites. The GIS that we have distributed allows all investigators to integrate a massive data set in an intuitive and interactive manner and should be a building block for many future studies. The STRATAFORM GIS was used as an example for the entire MG&G community at an NSF-sponsored workshop on MG&G databases (Mayer, 2001) Quantitative measurements of slope and sediment-type distributions will inevitably lead to improved models of shelf and slope development, the primary goal of the STRATAFORM program. Our initial results from the New Jersey margin indicate that pervasive ice scouring is evident further south than previously reported and may have impact on our overall understanding of the evolution of shelf stratigraphy. The ability to interactively explore large and complex data sets in a 3-D GIS has greatly facilitated our understanding of the seafloor

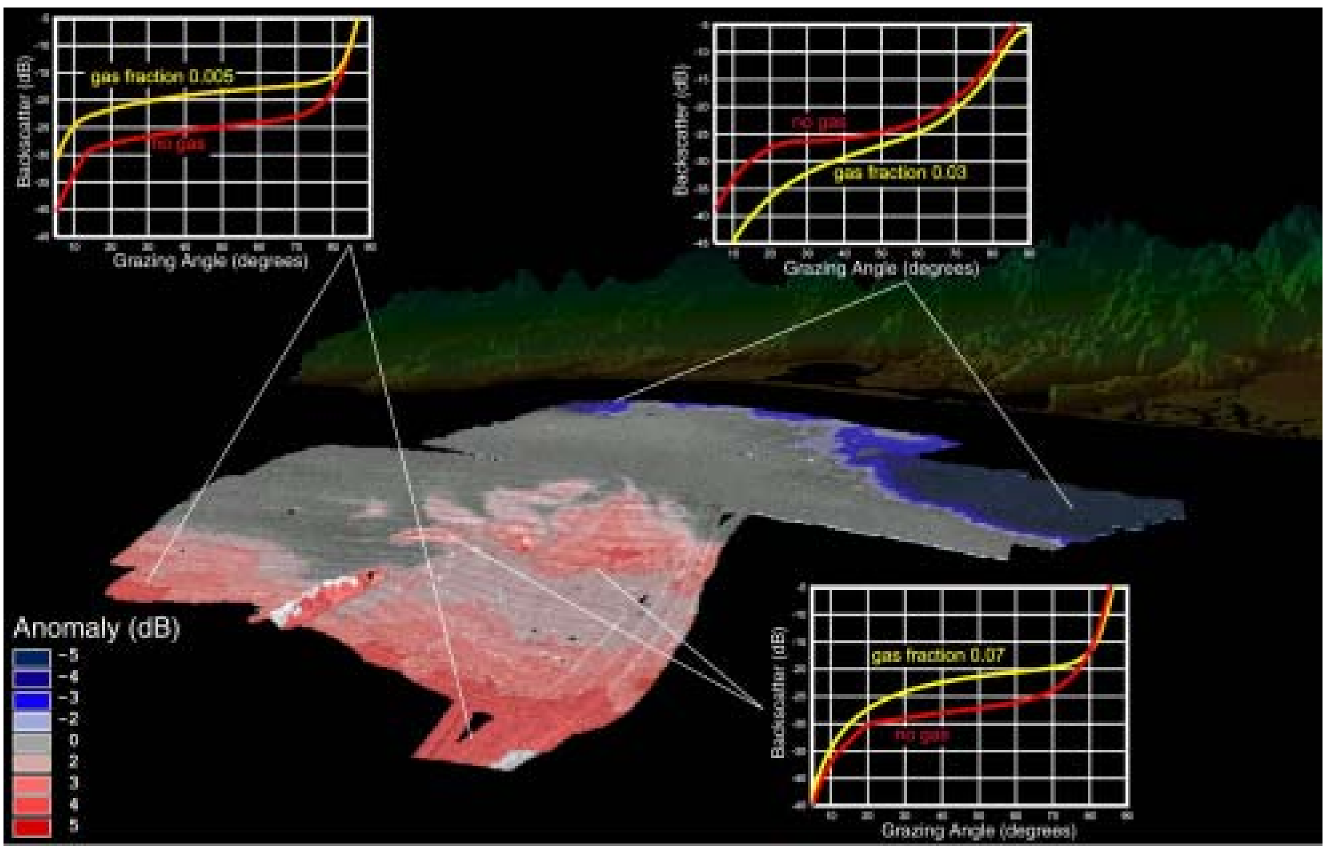

Figure 3. Plot of "backscatter anomaly" i.e. difference between the backscatter predicted from the physical properties at the site minus the measured backscatter. This is screen capture from interactive 3-D GIS. Including measured gas in backscatter model provides explanation for these anomalies.

processes at work in the Strataform areas and particularly their relationship to seafloor morphology. In addition, through the use of backscatter as a function of angle of incidence and wavelet transforms we hope to better understand the lateral changes in seafloor roughness and composition and, in particular, the role of gas in affecting seafloor and near subsurface backscatter.

TRANSITIONS

Our maps and data have been used by numerous investigators both in and out of STRATAFORM, including several other Navy programs (e.g., SWARM, NRL, GEOCLUTTER). Our processing and visualization software is being used by NAVO, NRL, NOAA, USGS, the Canadian Hydrographic Service, the Royal Australian Navy, as well as a number of universities and private sector companies (Shell, Exxon, Woodside Petroleum, BP, WAPET Petroleum). PetroBras is looking at the new techniques that we have developed for looking at the signature of gas in multibeam data as a potential exploration and hazard identification tool.

RELATED PROJECTS

UNH Joint Hydrographic Center – a NOAA sponsored program that provides base support for general research in the field of ocean mapping. DURIP sponsored multibeam sonar at SUNY Stony Brook (with Roger Flood – SUNY Stony Brook and Dale Chayes LDEO). "High-resolution Bathymetry and Backscatter of a High-Frequency Acoustics Test Area" – work of Panama City with Roger Flood.

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